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Docket No.: HO-P01426US2
(PATENT)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:
William T. Carpenter

Application No.: 09/773,815

Confirmation No.: 8585

Filed: January 31, 2001

Art Unit: 3673

For: METHOD OF MODIFYING THE AXIS OF ROTATION OF THE EARTH

Examiner: J. J. Kreck

APPEAL BRIEF

MS Appeal Brief - Patents
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

The fees required under 37 C.F.R. § 41.20(b)(2) are dealt with in the accompanying TRANSMITTAL OF APPEAL BRIEF.

This brief contains items under the following headings as required by 37 C.F.R. § 41.37 and M.P.E.P. § 1206:

I. REAL PARTY IN INTEREST

The real party in interest for this appeal is: William T. Carpenter, a U.S. citizen and resident of Houston, Texas.

II. RELATED APPEALS, INTERFERENCES, AND JUDICIAL PROCEEDINGS

There is an earlier First Board Decision in this case, *Ex Parte William T. Carpenter*, Appeal No. 2006-0089 are no other appeals, interferences, or judicial proceedings which will directly affect or be directly affected by or have a bearing on the Board's decision in this appeal.

III. STATUS OF CLAIMS

A. Total Number of Claims in Application

There are 10 claims pending in application, which are identified as claims 11-20.

B. Current Status of Claims

1. Claims canceled: Claims 1-10.
2. Claims withdrawn from consideration but not canceled: None.
3. Claims pending: Claims 11-20.
4. Claims allowed: None.
5. Claims rejected: Claims 11-20.

C. Claims On Appeal

The claims on appeal are Claims 11-20.

IV. STATUS OF AMENDMENTS

There are no outstanding amendments in the pending claims.

V. SUMMARY OF CLAIMED SUBJECT MATTER

Claim 11 is the only independent claim pending in the application. It relates to a method of modifying the axis of rotation of a planet by redistributing the mass in or on the crust of the planet. Such redistribution will change the axis of rotation.

VI. GROUNDS OF REJECTION TO BE REVIEWED ON APPEAL

The following grounds of rejection are presented for review on appeal:

Claims 11-20 have been rejected under 35 U.S.C. § 101 as lacking patentable utility.

Claims 11-20 have been rejected under 35 U.S.C. § 112 on the grounds that the specification does not reasonably provide enablement for calculating and determining modification of the axis of rotation relative to inertial space, and on the grounds of failing to enable selecting a desired orientation of an axis of rotation.

Claims 11-20 have been rejected under 35 U.S.C. § 103(a) as being unpatentable over Chao "Excitation of the Earth's Polar Motion due to Mass Variation in Major Hydrological Reservoirs" ("Chao Excitation").

VII. ARGUMENT

Claims 11-20 are currently pending. The examiner has twice rejected all pending claims under § 101 as lacking patentable utility; under § 112, first paragraph, as failing to comply with the enablement requirement; and under § 103(a) as unpatentable over Chao.

A. Utility

The examiner contends that the claimed invention lacks utility because the "Applicant provides no guidance on how to determine a climate pattern which would result from such a change, nor does applicant provide any guidance on how to determine whether a particular climate pattern would be beneficial." Office Action mailed July 19, 2007 at p. 5 (hereinafter "OA"). The examiner's rejection is not appropriate because the examiner is requiring the a level of detail in the estimated change to the climate pattern that is not required. *E.I. du Pont De Nemours and Co v. Berkley and Co.*, 977 F.2d 1247, 1260 (8th Cir. 1980) ("An invention does not lack utility merely because the particular embodiment disclosed in the patent lacks perfection or performs crudely."). Thus, the fact that the current state of climate modeling is "rough at best" does not support a rejection of the claimed invention. *See* OA at 5.

To establish a *prima facie* case that an invention is unpatentable because it is not useful, the examiner must establish that the claimed invention lacks both specific and

substantial utility. *In re Fisher*, 421 F.3d 1365, 1371 (Fed. Cir. 2005) (application must establish a specific and substantial utility for claimed invention). To satisfy the "specific" utility requirement, an asserted use must also show that the claimed invention can be used to provide a well-defined and particular benefit to the public. *Id.* The claimed invention provides such a benefit, namely altering the Earth's axis of rotation to alter the amount of light received during the earth's rotation.

The examiner posits a hypothetical on pages 4 and 5 of the Office Action mailed July 19, 2007. The hypothetical details how application of the claimed invention would change the incidence of light and the length of the day for a location. The examiner concedes the change would result in changes in the amount of solar energy at predictable locations. As the examiner points out, the change in the angle of rotation of the Earth would alter the amount of light received in summer and winter. These alterations are adequate utility. *Brooktree Corp. v. Advanced Micor Devices, Inc.*, 977 F.2d 1555, 1571 (Fed. Cir. 1992) (holding that "[t]o violate [35 U.S.C. §] 101 the claimed [invention] must be totally incapable of achieving a useful result"). As the Examiner's hypothetical clearly points out, the claimed invention is at least partially successful in achieving a useful result. *E.I. du Pont*, 620 F.2d at 1571. While the current state of the art in climate modeling does not provide the resolution the examiner suggests is necessary, the examiner fails to show any evidence that this level of resolution is necessary to show the claimed benefit. Because the examiner can not show the method is totally incapable of achieving a useful result, he has failed to meet his burden and thus his rejection of Claims 11-20 based on a lack of utility should be reversed.

B. Enablement

1. The examiner is barred from reopening prosecution of the proceeding for consideration of matters previously decided by the Board.

The Board of Patent Appeals and Interferences (the "Board") has previously adjudicated enablement in this case. When a decision by the Board has become final for judicial review, the examiner is barred from reopening prosecution of the proceeding for matters already adjudicated. 37 C.F.R. § 1.198. The examiner argues that the bar of § 1.198 does not apply because the present enablement rejection "sets forth new matters that were not presented in the appeal of July 5, 2005 … and therefore [is] not 'already adjudicated' by the Board.'" OA at p. 12. Additionally, the examiner argues that the Board did not hold the

claims enabled, but only held that the examiner failed to provide a *prima facie* case of non-enablement. *Id.*

The examiner is incorrect that enablement was not previously adjudicated and that the present enablement rejection is not barred. First, all the Board ever considers with respect to rejections is whether the examiner has met his burden of proof. The examiner's reasoning would render § 1.198 never applicable. That the examiner earlier failed to prove non-enablement does not render §1.198 inapplicable to adjudication of that failure. Second, to the extent the foregoing reasoning is unpersuasive, the Board in this case specifically held that claims were enabled. *Ex Parte Carpenter*, Decision on Appeal, Appeal No. 2006-0089 (hereinafter "First Board Decision") at pp. 5-6. Third, what the examiner characterizes as "new matters" is at best a reformulated effort to re-address the matter of enablement. Such an effort is akin to losing a trial then seeking to re-try the case with different witnesses. Thus, the enablement rejection by the examiner is procedurally improper and must be reversed.

2. Even were the examiner not barred from re-opening enablement, the enablement rejection is substantively erroneous and should be reversed on the merits.

It is well-established that the test for enablement is whether the specification teaches those skilled in the art how to make and use the full scope of the claimed invention without undue experimentation. *In re Wright*, 999 F.2d 1557, 1561 (Fed. Cir. 1993); *In re Fisher*, 427 F.2d 833, 839 (CCPA 1970). The examiner has the initial burden to establish a reasonable basis to question the enablement provided for the claimed invention. *In re Wright*, 999 F.2d at 1562 (examiner must provide a reasonable explanation as to why the scope of protection provided by a claim is not adequately enabled by the disclosure).

It is well settled that as long as the specification discloses at least one method for making and using the claimed invention that bears a reasonable correlation to the entire scope of the claim, then the enablement requirement of § 112 is satisfied. *In re Fisher*, 427 F.2d 833, 839 (CCPA 1970). Failure to disclose other methods by which the claimed invention may be made does not render a claim invalid under 35 U.S.C. § 112. *Spectra-Physics, Inc. v. Coherent, Inc.*, 827 F.2d 1524 (Fed. Cir. 1987).

The Board, in its prior decision, concluded that making and using the claimed invention was enabled. First Board Decision at 6 ("[W]e have no doubt that one skilled in the pertinent art would be able to calculate a moment of stability required to cause a desired character of rotation and otherwise perform the claimed method without resort to undue experimentation."). Thus, the examiner's rejection is improper and must be reversed.

Notwithstanding the foregoing, The examiner first contends that the claimed invention is not enabled because there is no evidence that the Earth's axis can be altered "relative to inertial space." OA at pp. 6-7. This contention fails to establish a prima facie case of lack of enablement for two reasons: (1) the claimed invention does not relate to altering the axis of rotation relative to inertial space and (2) the "orientation of the axis" of rotation cannot be "relative" to inertial space, and the examiner's contrary perception reflects merely a misunderstanding of terminology.

In the requirement for information dated January 20, 2007, the examiner posed the following question: "Does the "orientation of the axis" refer to (a) the orientation of the axis of the planet relative to inertial space; or (b) orientation of the axis with respect to the crust of the planet?" In reply to the requirement for information dated March 28, 2007, Applicant stated "'[t]he orientation of the axis of rotation of a planet' refers to any axis orientation that a user of the method might desire." The examiner has interpreted this response, and the specification, to mean that the orientation of the axis of rotation of a plant can be "relative to inertial space." This is incorrect. Consistently and throughout the specification, the axis of rotation is described as being "relative to the body of the planet, or *in* inertial space." *See* Specification p.1, ins. 6-7; p.3, ins. 27-28; p. 4, ins. 11-12; p.6, ins. 8-9 (emphasis added). It is clear from the specification that the planet is "in inertial space" and orientation of the axis is relative to some other object, "in inertial space." Specification p. 5 ins. 23-26 ("[S]ince [the Earth] is rotating in inertial space....change in the axis of rotation changes the relationship to the Sun, Moon, and other planets...."). The examiner is has incorrectly interpreted the claim to require the orientation of the axis to be "relative to inertial space."

To say that the axis of rotation is "relative to inertial space" is to misuse the term "inertial space." "Inertial space" is the background reference that is provided by the phenomenon of inertia. Physical measurements related to inertial space are limited to acceleration. There does not exist such a thing as as measuring an object's position with

respect to inertial space and no such thing exists as measuring an object's velocity with respect to inertial space. McGRAW-HILL DICTIONARY OF SCIENTIFIC AND TECHNICAL TERMS 1070 (6th ed. 2003) (defining inertial space "a coordinate system or frame of reference defined with respect to the stars whose apparent position relative to surrounding stars appear to be fixed or unvaring for long periods of time"). Thus, it is impossible to measure the orientation of the axis "relative" to interial space as suggested by the examiner. This also explains why the references cited by the examiner do not make mention of changes in the orentation of the axis relative to inertial space—changes in orentation of the axis must be relative to some object in inertial space.

The examiner next contends that the claimed invention is not enabled because the claimed "selecting a desired orientation of the axis of rotation" implies pursuit of "a desired climate," and because the specification fails to "provide[]any examples of a desired change in the axis of rotation. " OA at pp. 8-9. This reasoning fails to establish a *prima facie* case of non-enablement. The examiner's rejection for the reason that Applicant has not provided any examples of a "desired change in the axis of rotation" misses the purpose of the enablement requirement.

The enablement requirement under Section 112, first paragraph, does not require or mandate that a specific example be disclosed. *In re Borkowski*, 422 F.2d 904, 908 (C.C.P.A. 1970). The only requirement is that the claimed invention be disclosed in such manner that one skilled in the art would be able to practice it without undue experimentation. *Id.* Thus, the examiner's contention that the Applicant has failed to provide any examples of a desired change in the axis of rotation is baseless.

It is notable that the examiner himself details a hypothetical that he acknowledges would result in changes to the climate pattern. OA at pp. 4-5. Using the examiner's hypothetical of modifying the orientation in such a manner such that the geographic North Pole moves southward in a direction opposite to the prime meridian, one of ordinary skill in the art would be able to calculate the resulting changes in the angle of the sun's rays, the hours of daylight, and the changes to the seasons (summer, winter, spring, fall), as the examiner concedes. Thus, one of skill in the art would be able to calculate the changes to the climate pattern, on a macro scale. *In re Hayes Microcomputer Prods. Inc. Patent Litig.*, 982 F.2d 1527, (Fed. Cir. 1992) (holding disclosure such that one skilled in the art would

understand what is intended and know how to carry it out is sufficient). Further still, elsewhere in the OA, in rejecting the claimed invention under §103, the examiner implicitly concedes enablement by arguing that "selecting a desired character of rotation" would be obvious to one of ordinary skill based on the prior art. OA at pp. 9-11.

In sum, the §112 rejection appears based on the examiner's concern about resolving how the selected changes might affect disparately located people around the globe, not how to affect the changes. Such concern confuses §112 with geopolitical debate about how to allocate a plant's solar resources. For the foregoing reasons, the examiner failed to make out a *prima facie* case of non-enablement, and examiner's rejection should be reversed.

C. Obviousness

1. The examiner is barred from re-arguing obviousness because the argument has been previously considered and rejected by the Board.

Again, when a decision by the Board on appeal has become final for judicial review, the examiner is barred from reopening prosecution of the proceeding for matters already adjudicated. § 1.198. The examiner's obviousness rejection based on Chao Excitation is merely cumulative of an obviousness rejection previously reversed by the Board. First Board Decision at 11. Therefore, the present obviousness rejection by the examiner is procedurally improper and must be reversed.

While the Chao Excitation reference was not relied on in the earlier rejection, the Chao Excitation reference cited by the examiner in the instant § 103 rejection is merely cumulative of the Chao reference "Anthropogenic Impact on Global Geodynamics due to Reservoir Water Impoundment", *Geophysical Research Letters*, vol. 22, no. 24, pp. 3529-3532 (December 15, 1995)) (hereinafter "Chao Anthropogenic") that the Board previously determined was not sufficient to sustain the examiner's obviousness rejection. First Board Decision at 9-10. Specifically, the prior art in Chao Excitation relied upon by the examiner in the instant rejection is a subset of the prior art relied upon by the examiner in the earlier, reversed rejection based on Chao Anthropogenic. The Examiner has merely re-urged the same argument but with a materially same reference:

> Chao [Excitation] has computed the polar motion excitation produced by a host of major hydrological changes including those due to major artificial

> reservoirs in the world competed before 1986. Building upon the latter, we will in this paper compute and discuss not only the polar motion excitation but also [length-of-day] and low-degree gravitational changes due to a more complete and up-to-date list of major reservoirs.

Chao Anthropogenic at 3529. Chao Anthropogenic is a continuation of the author's previous studies on the hydrological excitation of the Earth's polar motion taking into account the effect of water mass variations of reservoirs that have time scales longer than one month. Chao Anthropogenic, abstract.

Because the prior art in Chao Excitation is cumulative of the prior art in Chao Anthropogenic, and because the Board has previously reversed an obviousness rejection based on Chao Anthropogenic, the obviousness rejection based on same art recited in Chao Excitation is improper and should be reversed.

2. The examiner has failed to establish a *prima facie* case of obviousness because the references do not teach or suggest all the claim limitations.

Aside from § 1.198, the examiner's obviousness rejection based on Chao Excitation fails to make on the merits a *prima facie* case of obviousness. Without a *prima facie* case of obviousness, any rejection under 35 U.S.C. § 103 is improper and should be reversed. *In re Fine*, 837 F.2d 1071, 1074 (Fed. Cir. 1988).

To establish a prima facie case of obviousness, three basic criteria must be met. First, there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference or to combine reference teachings. Second, there must be a reasonable expectation of success. Finally, the prior art cited must teach or suggest all the claim limitations. *See* M.P.E.P. § 2143. Without conceding the second criteria, Applicant asserts that the rejection does not satisfy the first and third criteria.

The Examiner concedes that Chao Excitation fails to explicitly discloses many of the claimed steps in independent Claim 11. OA at 10-11. The Examiner attempts to cure this deficiency by conclusorily stating that because one skilled in the art would know to measure the transient changes in polar drift or Chandler wobble based on changes in reservoirs, one skilled in the art can choose the size and location of a mass required to effect a desired change in the orientation of the axis of rotation. However, Chao merely identifies a problem

without posing any solution. The examiner's conclusory statements do not establish that Chao Excitation teaches or suggests all limitations of the claimed invention.

As discussed above, the Board previously determined that Chao Anthropogenic was not sufficient to sustain the examiner's obviousness rejection. First Board Decision at 11. In that prior decision, the Board correctly characterized Chao Anthropogenic as "looking at humans' impact on global geodynamics due to reservoir impoundment since 1950." *Id.* at 9. The Board further noted that "[a]lthough [Chao Anthropogenic] recognize[s] that the Earth's axis of rotation is slowly changing and that such changes induced by both humans and nature will alter the Earth's living environment, [it does not] contemplate[], teach[] or suggest[] the particular method of claims 11 through 20 on appeal as a solution to the Earth's changing rotational orientation." *Id.* at 9-10. Chao Excitation is consistent with this characterization. Chao Excitation merely extends the changes induced by humans and nature over a longer time period. Thus, Chao Excitation, like Chao Anthropogenic, does not contemplate, teach, or suggest the particular method of Claims 11 through 20 on appeal as a solution to changing the Earth's rotational orientation.

Chao Excitation, like Chao Anthropogenic, fails to "teach or suggest appellant's claimed pro-active method involving the steps of" (1) measuring the mass of a planet, (2) determining the center of mass of the planet, (3) characterizing the orientation of the axis of rotation of the planet, (4) selecting a desired orientation of the axis of rotation, (5) calculating a moment of stability required to cause the desired orientation of the axis of rotation, (6) determining the position and a mass of compensating substance sufficient to effect the moment of stability, and (7) positioning the mass in the position.

For the reasons stated above, the examiner's rejection based upon 35 U.S.C. § 103 is improper. Thus, the rejection should be reversed.

VIII. CLAIMS APPENDIX

A copy of the claims involved in the present appeal is attached hereto as Appendix A.

IX. EVIDENCE APPENDIX

Copies of the references addressed in this brief are included in Appendix B.

X. RELATED PROCEEDINGS APPENDIX

A copy of the First Board Decision is attached hereto as Appendix C.

Dated: May 9, 2008

Respectfully submitted,

By____________________

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APPENDIX A

1-10. (Cancelled).

11. (Currently Amended) A method of modifying the orientation of the axis of rotation of a planet comprising the steps of:

measuring the mass of a planet;

determining the center of mass of the planet;

characterizing the orientation of the axis of rotation of the planet;

selecting a desired ~~character of rotation~~ orientation of the axis of rotation;

calculating a moment of stability required to cause the desired ~~character of rotation~~ orientation of the axis of rotation;

determining a position and a mass of compensating substance sufficient to effect the moment of stability; and

positioning the mass in the position.

12. The method of claim 11 in which the position of the compensating substance is positioned in an underground cavity.

13. The method of claim 11 in which the position of the compensating is positioned in an above ground cavity.

14. The method of claim 11 in which the substance is solid.

15. The method of claim 11 in which the substance is a liquid.

16. The method of claim 12 in which the substance is a liquid.

17. The method of claim 13 in which the substance is liquid.

18. The method of claim 15 in which the liquid is water.

19. The method of claim 16 in which the liquid is water.

20. The method of claim 17 in which the liquid is water.

APPENDIX B

1. Excitation of the Earth's Polar Motion due to Mass Variation in Major Hydrological Reservoirs.

2. Anthropogenic Impact on Global Geodynamics due to Reservoir Water Impoundment.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 93, NO. B11, PAGES 13,811–13,819, NOVEMBER 10, 1988

Excitation of the Earth's Polar Motion due to Mass Variations in Major Hydrological Reservoirs

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Previous studies on the hydrological excitation of the Earth's polar motion have neglected the effect of water mass variations of hydrological reservoirs that have time scales much longer than a month. To remedy this, the present paper calculates the polar motion excitation caused by variations in major natural lakes, the impoundment in artificial reservoirs, and the depletion of a major groundwater aquifer. It is found that (1) the annual water mass variation in natural lakes contributes a significant fraction in the total hydrological excitation of the annual wobble, (2) the hydrological reservoirs have been negligible in the Chandler wobble excitation, and (3) the contribution of hydrological reservoirs to the total secular polar drift has been negligible in this century due to fortuitous cancellation among reservoirs.

1. INTRODUCTION

The conservation of angular momentum dictates that changes in the Earth's inertia tensor due to mass redistribution will cause, or "excite," variations in the Earth's rotation. The present paper examines the excitation of the polar motion, or the shift of the Earth's rotational axis in a geographical reference frame, by some recorded variations in hydrological reservoirs, including major natural lakes, artificial reservoirs, and a groundwater aquifer. We shall focus on the excitation of the annual wobble, the 14-month Chandler wobble, and the secular drift of the mean pole in the polar motion.

A "significant" polar motion excitation mechanism can be defined here as one that can produce an excitation of the order of 1 milliarcsecond (mas). The latter, corresponding to a 3-cm shift in the rotational axis on the Earth's surface, is about the precision of modern measuring techniques [e.g., *King*, 1987] and represents roughly 1% of the overall magnitude in the observed excitation. Qualitatively, to be of significance in the polar motion excitation, a surface mass redistribution must be sufficiently large in both the transported mass and the effective transportation distance. For example, intercontinental shipping of petroleum and goods is not significant because of its relatively small mass. Formation of polar sea ice, floating icebergs, or ocean thermal effects can be dismissed because the distance involved (a matter of meters) is small compared to the Earth's radius. As significant surface excitation mechanisms for the polar motion, only the atmospheric and hydrological transport of masses have been examined.

Atmospheric excitation of polar motion has been under study as global meteorological observations improve [e.g., *Munk and Hassan*, 1961; *Wilson and Haubrich*, 1976; *Wahr*, 1983; *Barnes et al.*, 1983; *Dickey et al.*, 1986]. It is known to be responsible for most of the observed annual wobble excitation; the remaining can presumably be accounted for by continental hydrological variations. The study of the latter, since the work by *Van Hylckama* [1970], has not progressed appreciably until recently [*Hinnov and Wilson*, 1987; *Chao et al.*, 1987; *Kuehne and Wilson*, 1988; *Chao and O'Connor*, 1988*b*]. However, large uncertainties and discrepancies exist among conventional hydrological data sets as well as in hydrological modeling of the water budget. The conventional data, especially those of the northern hemispheric snow storage, have been subject to systematic misrepresentation that translates into large estimation errors, as pointed out by *Chao and O'Connor* [1988*b*], but with the advent of satellite remote sensing techniques, such errors can be greatly alleviated [*Chao et al.*, 1987].

The largest uncertainty in hydrological modeling, apart from the subsurface groundwater variations whose global monitoring is presently unattainable, lies primarily in the manner in which excess water runs off to the ocean. Previous studies on the global hydrological excitation of polar motion, of necessity, adopt a certain (analytical) runoff model and assume its applicability to all regions on land. These models, typically with a time scale of about a month, do not take into account the water variations in hydrological reservoirs (through, for example, excessive rainfall or evaporation) that have periods much longer than a month. The present paper is an attempt to remedy this. In this sense, our results are "corrections" (although not necessarily small, as we will see) to previous estimates of hydrological excitation of polar motion.

A hydrological reservoir, with dimensions much smaller than the Earth's radius, will be treated as a point mass. Its variation $\Delta m(t)$ can assume positive or negative values depending on whether the reservoir is gaining or losing water. The polar motion excitation function ψ can be expressed in terms of its x and y components along the Greenwich meridian and the 90°E meridian, respectively: $\psi \equiv \psi_x + i\psi_y$. It will be given in units of milliarcseconds (mas, 1 mas $\simeq 4.85 \times 10^{-9}$ rad). The expression for ψ caused by a surface mass redistribution is given by, for example, *Munk and MacDonald* [1960, p. 106]. For a point mass Δm located at latitude θ and longitude λ it reduces to

$$\psi(t) = -\Delta m(t) \sin\theta \cos\theta \exp(i\lambda)/(J_2 M) \qquad (1)$$

where $M = 6.0 \times 10^{24}$ kg and $J_2 = 1.083 \times 10^{-3}$ are the Earth's mass and dynamic oblateness, respectively. Equation (1) applies when (1) $\Delta m \ll J_2 M$, and (2) the Earth responds elastically to the loading/unloading. The latter limits our time scale to within a few decades. Thus long-term changes, such as those in large ancient lakes or polar and alpine glaciers due to slow climatic changes, are beyond the present scope. For a

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Paper number 88JB03295.

dynamic changes in

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TABLE 1. World's Largest Lakes and Some Medium-Sized Lakes With Large Variations

Name[a]	Continent	Mean Area, $\times 10^3$ km^2	Mean Depth, m	(θ, λ)[b]
1, Caspian Sea (c)	Asia-Europe	374.0	182	(42.0, 50.5)
2, Superior (d)	North America	82.4	149	(47.5, −87.6)
3, Victoria (d)	Africa	69.4	40	(−1.5, 33.0)
4, Aral Sea (c)	Asia	66.5	16	(45.0, 60.0)
5, Huron (d)	North America	59.6	59	(45.0, −82.5)
6, Michigan (d)	North America	58.0	85	(43.5, −87.0)
7, Tanganyika (d)	Africa	32.9	572	(−6.0, 29.5)
8, Great Bear (d)	North America	31.8	73	(66.0, −121.0)
9, Baikal (d)	Asia	31.5	740	(53.0, 107.8)
10, Malawi (d)	Africa	29.6	273	(−12.0, 34.3)
11, Great Slave (d)	North America	28.4	62	(61.5, −114.0)
12, Erie (d)	North America	25.7	19	(42.1, −81.2)
13, Winnipeg (d)	North America	24.5	13	(52.5, −98.5)
14, Ontario (d)	North America	19.7	86	(43.8, −78.0)
15, Ladoga (d)	Europe	17.7	51	(61.0, 31.5)
16, Balkhash (c)	Asia	17.4	6	(46.5, 76.0)
17, Pantanal (d)	South America	0–99	0–0.7	(−22.0, −57.0)
18, Tonle Sap (d)	Asia	3–30	2–10	(12.8, 104.2)
19, Chad (c)	Africa	10–24	2–4	(13.5, 14.0)
20, Eyre (c)	Australia	0–8	0–3	(−29.0, 137.3)
21, Great Salt (c)	North America	5.7	5	(41.0, −112.5)

[a](c), closed; (d), drainage.
[b]Mean latitude θ (positive for north and negative for south) and mean longitude λ (positive for east and negative for west), in degrees.

treatment of those a viscoelastic Earth model should be more pertinent [e.g., *Gasperini et al.*, 1986].

The geographical weighting function in (1), $\sin\theta\cos\theta \exp(i\lambda)$, is the spherical harmonic of degree 2 and order 1. It is antisymmetric with respect to both longitude and latitude. For example, two identical $\Delta m(t)$ situated on the same latitude but 180° apart in longitude will cancel each other in their contributions to ψ. Further, because of the negative sign in (1), a positive Δm located on longitude λ will push the excitation pole to the opposite longitude ($\lambda + 180°$), while a negative Δm will do the opposite, pulling the pole toward λ. Physically, this results from the action of the centrifugal force.

To conserve water mass, we shall assume that the reservoirs exchange their water ultimately with the ocean. The effective transportation distance is thus comparable to the Earth's radius. The resultant change in sea level is further assumed to be uniform. This produces additional contribution to ψ which will be evaluated according to *Chao and O'Connor* [1988*a*]. This "ocean correction" is usually small, typically of the order of 5%, because of the widespread distribution of the oceans as opposed to the point masses under consideration.

We are now in a position to give a criterion for a given reservoir to be significant (see above) in polar motion excitation. Apart from the polar and equatorial regions (where the weighting function in (1) approaches zero), the magnitude $|\psi|$ is of the order of $\Delta m/(2MJ_2)$. For $|\psi|$ to exceed 1 mas, the variation Δm needs to be at least 6×10^{13} kg, corresponding to a water volume of 60 km^3. Thus our rule of thumb is to include Δm that is larger than $\sim 10^{13}$ kg, and we will strive to be exhaustive insofar as observational records and documents are available.

The Earth's rotational speed (or equivalently, the length of day, LOD) and gravitational field can also be changed by mass redistributions. These will not be studied in this paper because of the small magnitude. For example, it can be shown [cf. *Chao et al.*, 1987; *Chao and O'Connor*, 1988*b*] that a surface point mass variation of 10^{14} kg can change LOD by no more than 2 μs. This is 1–2 orders of magnitude smaller than the modern measurement accuracy. The small magnitude is a consequence of the fact that the LOD change does not enjoy the dynamic magnification of the factor $1/J_2$ as ψ does (see equation (1)). The same mass variation can change the J_2 coefficient in the Earth's gravitational field by no more than 10^{-11}, which is of marginal importance compared to those due to other known causes [e.g., *Yoder et al.*, 1983; *Rubincam*, 1984; *Chao and O'Connor*, 1988*b*].

2. NATURAL LAKES

Natural lakes are of two kinds: drainage and closed. Drainage lakes are simply "wide places in a river," while closed lakes have no outlet to the ocean. Table 1 lists the world's largest natural lakes and some medium-sized lakes (and marshes) with large known variations. The majority of these large lakes cluster about the 45° latitude, making their variations potentially most effective in exciting the polar motion.

Typically, the level of a lake varies seasonally, while modulated year to year by interannual variations. The interannual modulation can be quite large, especially in closed lakes. As a result, these changes contribute to the excitation of all observable components in the polar motion: the seasonal signal excites the annual wobble, whereas the interannual variations contribute to the excitation of the Chandler wobble and polar drift. They will be studied to various degrees of certainty depending on the availability of records.

2.1. *Excitation of Annual Wobble*

To obtain the annual wobble excitation, we first calculate the water mass variation $\Delta m(t)$ from lake level data or mean-monthly water budget; the procedure for each lake will be described below. Using Table 1, $\Delta m(t)$ is then substituted into (1) to calculate $\psi(t)$. The annual signal is subsequently extracted from $\psi(t)$ by a least squares fit to $\psi_x(t)$ and $\psi_y(t)$ individ-

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ually. Finally, the results are converted into the prograde (ψ^+) and the retrograde (ψ^-) components for January 1 [*Munk and MacDonald*, 1960] to facilitate comparison with the observed and previously published estimates. These ψ^+ and ψ^- results, as summarized in Table 3 and plotted in Figure 5, will be discussed in section 5.

The level of the five North American (NA) Great Lakes (Superior, Michigan, Huron, Ontario, and Erie) have been well recorded since 1860. Figure 1 shows the monthly averages for the period 1962–1986. The mean values have been removed. The data were provided by the Great Lakes Acquisition Unit, National Ocean Service, National Oceanic and Atmospheric Administration, Rockville, Maryland (H. A. Lippincott, personal communication, 1987). The left-hand scale of Figure 1 gives the water level variation, while the right-hand scale gives the corresponding mass variation. Their combined annual wobble excitation is presented in Table 3 and Figure 5. The interannual variations will be examined in 2.2 and 2.3.

The level observations for the Canadian North West (NW) Plains lakes are less uniform, suffering from frequent gaps. Here we study the three largest lakes in the region (Great Bear, Great Slave, and Winnipeg). The data were provided by the Water Resources Branch, Water Survey of Canada, Ottawa, Ontario (D. Anderson, personal communication, 1987). The mean-monthly variations, obtained by averaging for each month of the year over the last two decades, are displaced in Figures 2*a*–2*c*; the scales are similar to Figure 1. As the NA Great Lakes, the high water occurs in mid-year with a progressive phase delay as the latitude increases. However, their combined contribution to the annual wobble excitation (see Table 3) is much smaller in magnitude as a result of the much smaller Δm and higher latitudes. Inclusion of other (smaller) lakes in the region (notably Athabasca, Winipegosis, and Manitoba) can somewhat increase this contribution but presumably by no more than 20% judging from their area.

The Caspian Sea is by far the world's largest lake. Its mean-monthly variation in level and water mass is presented in Figure 2*d*. It is calculated from the mean-monthly water budget given by inflow plus precipitation minus evaporation. The river inflow (predominantly from the Volga) is taken from *Van der Leeden* [1975]; the groundwater inflow, known to be very small [*Zemljanitzyna*, 1973], is ignored. Estimates for the evaporation and the (much smaller) precipitation are given by *Evsev* [1969]. The condition for a balanced mean-year budget is satisfied.

The mean-monthly water variation for the Aral Sea, shown in Figure 2*e*, is similarly calculated. The annual and seasonal budget for individual years is known to be quite variable. The

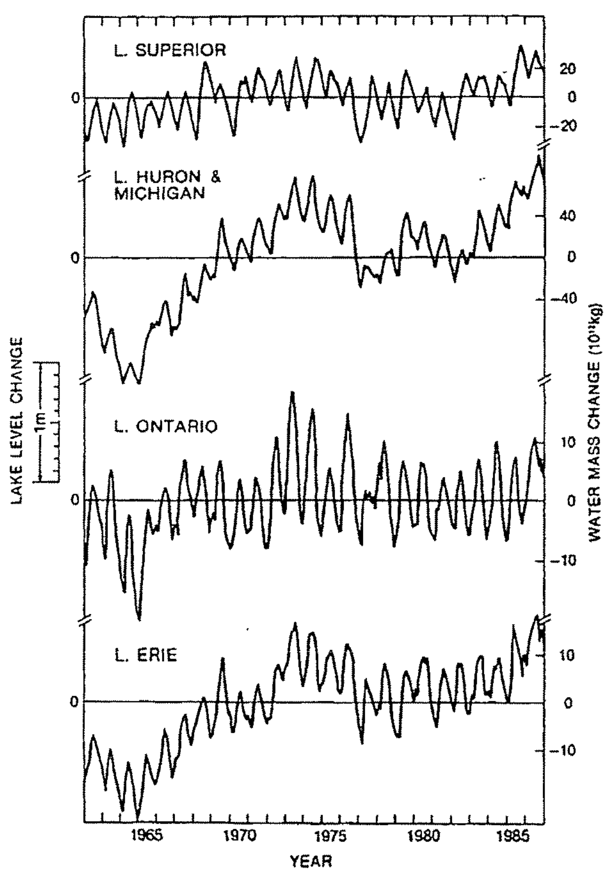

Fig. 1. The monthly variations in water level (left-hand scale) and water mass (right-hand scale) for the five North American Great Lakes, 1962–1986. Mean values have been removed.

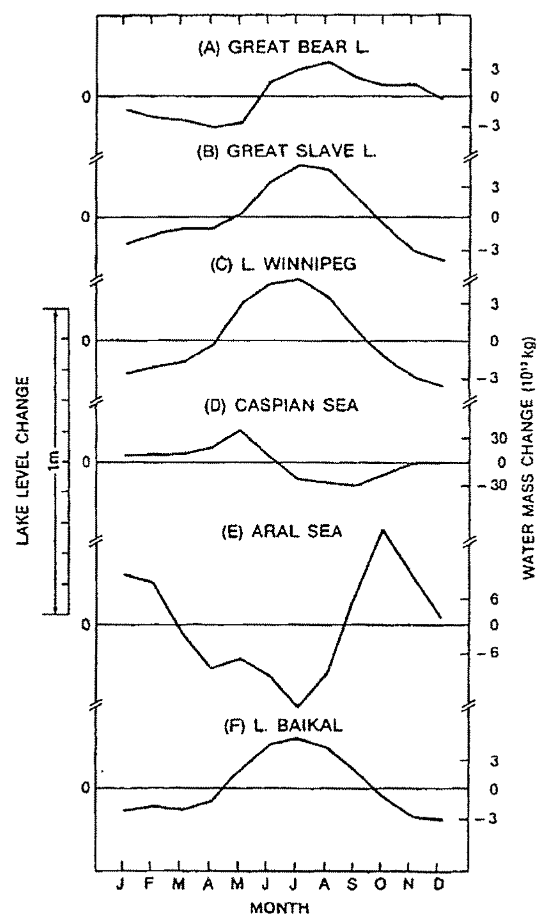

Fig. 2. The mean-monthly variations in various natural lakes. The scales are similar to Figure 1.

dominant inflow comes from the Amur Darya; the mean-monthly behavior of precipitation and evaporation is modeled in accordance with that of northeastern Caspian Sea in light of the proximity and similar climatic setting of the two lakes [*Evsev*, 1969].

The mean-monthly water variation for Lake Baikal is shown in Figure 2*f*. It is based on level data collected during 1959–1971, given by *Afansyev and Leksakova* [1973].

For Lake Ladoga, the Pantanal, and the Tonle Sap the seasonal water mass variations are calculated or estimated according to records given by the *Encyclopaedia Britannica* and *UNESCO* [1978]. These values are considered nominal and are subject to relatively large uncertainties. The Pantanal, the world's greatest (seasonal) freshwater marsh, has a peak-to-peak Δm of some 6.5×10^{13} kg due to the annual flooding of the Paraguay River. The Tonle Sap has a somewhat larger Δm, roughly 8×10^{13} kg, as a result of the summer monsoon. Since these two excitations happen to oppose, and hence largely cancel each other (cf. Table 3 or Figure 5), the systematic errors in their amplitude estimates are also largely cancelled.

Other lakes will not be examined individually in similar detail for their annual wobble excitations. The three East African lakes (Victoria, Tanganyika, and Malawi) are ineffective in exciting polar motion because of their proximity to the equator: a typical peak-to-peak annual variation of 50 cm in the lake levels [*Lamb*, 1966] only amounts to $|\psi|$ amplitudes of 0.014, 0.027, and 0.048 mas, respectively. Finally, judging from the small excitations for lakes Baikal and Ladoga, one should not expect a significant contribution from Lake Balkhash or other smaller (closed) lakes in Table 1.

2.2. *Excitation of Chandler Wobble*

Chandler wobble excitation will be studied in the frequency domain in terms of spectral power around the Chandler frequency. The Chandler frequency, 0.84 cycle per year (cpy), is where the highest signal-to-noise ratio in the observed data resides. We shall only deal with the five NA Great Lakes whose level data are in the form of uniform multiyear series.

First, the seasonal signals (from the least squares fit performed in section 2.1) are subtracted from $\psi(t)$. Then the Hann-windowed power spectrum are computed. We do this for the period 1962–1986 and plot the spectra, in Figure 3, against the observed Chandler excitation spectrum for the same period. The latter is adopted from *Chao* [1987] using a polar motion series published by the Bureau International de l'Heure (BIH); a mean, a linear trend, as well as the annual wobble (from a least squares estimation) have been subtracted beforehand. The frequency range -1.5 to 1.5 cpy is shown, where positive frequencies correspond to the prograde component ψ^+, and negative frequencies correspond to the retrograde component ψ^-. The vertical line at $+0.84$ cpy indicates the Chandler frequency.

From Figure 3, it is seen that around the Chandler frequency the power of the Chandler excitation due to the interannual mass variation of the NA lakes is about 40 dB too small to drive the observed Chandler wobble during 1962–1986. This will be further discussed in section 5.

2.3. *Polar Drift*

For mass redistributions, the polar motion excitation function $\psi(t)$ in equation (1) gives the position of the instantaneous axis around which the rotational pole wobbles. Thus $\psi(t)$ is also the mean pole position as a function of time, known as the polar drift. Table 3 lists the estimated secular changes in the lake water mass (Δm) (described below), and the time of the occurrence (in this century). The resultant polar drift ψ, also presented in Table 3 and plotted in Figure 6, will be discussed in section 5.

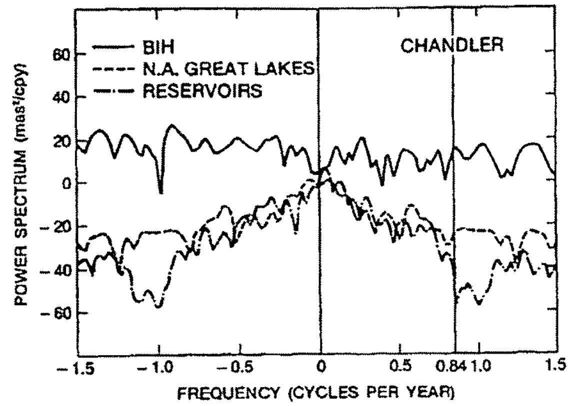

Fig. 3. The spectral power of the Chandler wobble excitation due to the five NA Great Lakes (dashed curve) and the artificial reservoirs (dot-dashed curve), in comparison with the observed Chandler power from BIH data (solid curve). The time span is 1962–1986. The vertical line indicates the Chandler frequency.

For the NA Great Lakes the levels fluctuate on a time scale of about 10–20 years, with amplitudes comparable to the annual peak-to-peak variations (Figure 1). The pole fluctuates accordingly, with an amplitude of about 4.5 mas. The lake levels have been risen since 1983 due to excessive rainfall, reaching record highs in many places by the end of 1986 [*Changnon*, 1987]. During this period the resultant polar drift rate was ~ 0.4 mas yr^{-1} toward 95°E. The Canadian NW Plains lake levels fluctuate in a similar fashion. For the same reasons as in section 2.1, the corresponding polar drift is only a small fraction of that due to the NA Great Lakes.

Estimates of secular variations in water mass for the other lakes are obtained from various sources, fragmentary in some cases: *Langbein* [1961], *Garbell* [1963], *Lamb* [1966], *Evsev* [1969], *Kalinin and Klige* [1973], *Shnitnikov* [1973], *Afansyev and Leksakova* [1973], *Van der Leeden* [1975], *UNESCO* [1978], and the *Encyclopaedia Britannica*. Although crude, these estimates provide a quantitative assessment of the importance of the contribution from each individual lake. The induced rise in the level of Lakes Victoria and Baikal as a result of the construction of the Owen Falls Dam (1954) and the Irkutsk Dam (1956), respectively, will be accounted for in the next section.

3. ARTIFICIAL RESERVOIRS

Gigantic water projects were begun in as early as the 1930s and have mushroomed since the 1950s. Table 2 lists all the major artificial reservoirs with nominal capacity larger than 10^{13} kg (or 10 km³) of water. The list is primarily according to *U.S. Department of the Interior* (USDI) [1983] with some additions from *Van der Leeden* [1975] (the two sources have some minor discrepancies). The total amount of water impounded reached some 2.6×10^{15} kg in 1986 (Figure 4*a*), by far the largest among all the water variations considered in

TABLE 2. World's Major Artificial Reservoirs With Water Capacity Greater Than 10 km³ (or 10^{13} kg)

Dam	Country	Capacity, $\times 10^{12}$ kg	Year Completed	$(\theta, \lambda)^a$
Akosombo	Ghana	148.0	1965	(7.0, 0.0)
Bennett WAC	Canada	70.3	1967	(56.0, −123.0)
Bhumiphol	Thailand	13.5	1964	(17.3, 99.0)
Boruca	Costa Rica	15.0	1983	(9.0, −83.3)
Bratsk	USSR	169.3	1964	(56.0, 102.0)
Bukhtarma	USSR	50.0	1960	(48.0, 84.0)
Cabora Bassa	Mozambique	63.0	1974	(−16.5, 32.0)
Cerros Colorados	Argentina	48.0	1973	(−38.5, −68.7)
Daniel Johnson	Canada	141.9	1968	(50.0, −69.0)
Emborcacao	Brazil	17.6	1981	(−18.3, −47.5)
Fort Peck	USA	23.6	1940	(47.8, −106.5)
Garrison	USA	30.1	1956	(47.5, −102.0)
Glen Canyon	USA	33.3	1964	(37.0, −111.7)
Grand Coulee	USA	11.6	1942	(48.0, −118.5)
Guri	Venezuela	136.0	1985	(7.0, −63.0)
High Aswan	Egypt	168.0	1970	(23.0, 32.5)
Hoover	USA	35.2	1936	(36.1, −114.5)
Irkutsk	USSR (Baikal)	46.0	1956	(53.0, 107.8)
Iroquois	USA/Canada	30.0	1958	(44.8, −75.3)
Itaipu	Brazil/Paraguay	29.0	1983	(−24.0, −54.2)
Itumbiara	Brazil	17.0	1980	(−18.5, −49.5)
Jenpeg	Canada	31.8	1975	(56.0, −98.0)
Kakhovka	USSR	18.2	1955	(47.5, 34.0)
Kapshagay	USSR	28.1	1970	(44.0, 78.0)
Kariba	Zambia/Zimbabwe	181.6	1959	(17.0, 28.0)
Keban	Turkey	31.0	1974	(38.8, 39.0)
Kenyir	Malaysia	13.6	1986	(5.3, 102.6)
Kossou	Ivory Coast	28.8	1972	(7.5, −5.7)
Krasnoyarsk	USSR	73.3	1967	(55.5, 92.0)
Kremenchug	USSR	13.5	1961	(49.3, 33.0)
LaGrande 2	Canada	61.7	1982	(53.7, −78.0)
LaGrande 3	Canada	60.0	1982	(53.7, −78.0)
Longyangxia	China	24.7	1983	(36.0, 101.0)
Mica	Canada	24.7	1972	(52.0, −118.3)
Mosul	Iraq	11.1	1982	(36.5, 43.0)
Nurek	USSR	10.5	1985	(38.3, 69.5)
Oahe	USA	29.1	1963	(45.0, −100.5)
Owen Falls	Uganda (Victoria)	204.8	1954	(−1.5, 33.0)
Rogun	USSR	11.6	1985	(38.3, 69.5)
Sanmenxia	China	35.4	1960	(34.5, 111.0)
Sao Felix	Brazil	50.6	1985	(−14.3, −48.7)
Saratov	USSR	12.9	1967	(51.0, 46.0)
Sayano-Shushensk	USSR	31.3	1980	(52.0, 93.0)
Sobridinho	Brazil	34.2	1981	(−10.0, −42.0)
Tabka	Syria	14.0	1976	(35.8, 38.3)
Tarbella	Pakistan	13.6	1976	(34.0, 72.5)
Toktogul	USSR	19.5	1978	(46.5, 76.0)
Tsimlyansk	USSR	23.8	1952	(48.0, 42.7)
Tucurui	Brazil	36.4	1983	(−3.7, −50.0)
Ust'-Ilimsk	USSR	59.4	1980	(57.5, 103.0)
Vilyuy	USSR	35.9	1967	(62.5, 111.5)
Volga-V.I. Lenin	USSR	58.0	1955	(54.0, 49.0)
Volgograd-22nd Congress	USSR	33.5	1958	(49.0, 45.0)

[a]Mean latitude θ (positive for north and negative for south) and mean longitude λ (positive for east and negative for west), in degrees.

this study. However, due to the widespread geographical locations of these reservoirs, there exists a great deal of cancellation among their polar motion excitations. Furthermore, unlike the natural lakes, many of the largest reservoirs are in the tropical regions, making them ineffective in the polar motion excitation.

Since the reservoir water impoundment has relatively small seasonal signals (if at all), we will focus on its excitation of the polar drift and Chandler wobble. Without detailed knowledge, we will assume that the reservoirs were steadily filled, starting at mid-year of the year of its completion, to their nominal capacity in the course of a year. Thus the cumulative amount of water impoundment is represented by a series of ramp functions, each one being 1 year in time span. It should be pointed out here that this simplified model does not appreciably affect our later inference: polar drift concerns itself solely with the long-term trend, while Chandler wobble excitation will be given in terms of the spectral power envelope (around the Chandler frequency) whose form only depends on the overall statistical nature of the water impoundment.

The computed polar motion excitation $\psi(t)$ is shown in Figure 4*b*. Apart from the early years before 1952, both $\psi_x(t)$ and $\psi_y(t)$ show a strong linear trend. Over the period 1952–1986, the total amount of polar drift attributable to the arti-

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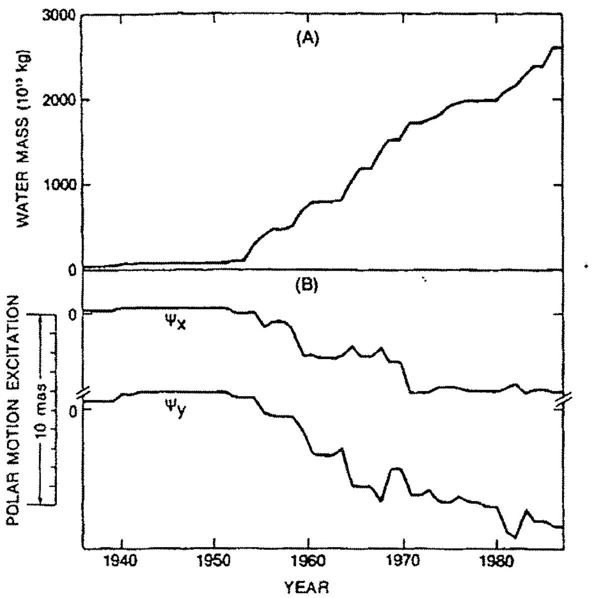

Fig. 4. For the artificial reservoirs: (*a*) the total water impoundment, and (*b*) the polar motion excitation function $\psi(t)$, ψ_x and ψ_y being the x and the y components, respectively.

ficial reservoirs is about 9.3 mas, corresponding to a rate of 0.27 mas yr^{-1}, in the direction of 122°W (Table 3).

The strong linear trend in $\psi(t)$ is not characteristic of a (two-dimensional) Brownian motion (whose standard deviation grows as $t^{1/2}$). This indicates that artificial water impoundment is more "deterministic" than random, a fact that is hardly surprising in light of the geography of human activities.

The power spectrum of $\psi(t)$ is then computed. The spectral envelope is characteristic of a frequency dependence of $f^{-\alpha}$ (f being the frequency). Best fit gives $\alpha = 3.5 \sim 4$ depending on the time and frequency span employed in the fit, again implying more closeness of $\psi(t)$ to a linear function (whose power spectrum is proportional to f^{-4}) than to a Brownian motion (whose power spectrum is proportional to f^{-2}). Incidentally, this is in contrast to the Chandler excitation due to earthquakes, whose spectral envelope is indistinguishable from that of a Brownian motion [*Chao and Gross*, 1987].

The Chandler excitation power spectrum for the artificial reservoirs, again Hann-windowed for 1962–1986, is shown in Figure 3. The dip in the power around ± 1 cpy is an artifact arising from our yearly ramp model. The power envelope, however, is of approximately the same level as that for the NA Great Lakes. This will be further discussed in section 5.

4. North American High Plains Groundwater Aquifer

Global mass variations in the underground water distribution are virtually unknown. In one case, however, this variation has been well documented to have exceeded 10^{14} kg.

The High Plains Aquifer is the principal source of water in the midwest United States, one of the world's major irrigated agricultural areas. The aquifer, geologically consisting mainly of the Ogallala Formation, underlies about 450,000 km^2 in area and contains about 4.0×10^{15} kg of drainable water. The development of this groundwater for irrigation was started in the 1940s and has steadily intensified since then, as summarized by *Gutentag et al.* [1984]. The rate of groundwater pumpage far exceeds the rate of natural replenishment: by 1980 more than 2×10^{14} kg (about 5% of the drainable water) has already been depleted from the aquifer and lost to the atmosphere by evaporation and ultimately to the ocean.

Table 11 of *Gutentag et al.* [1984] presents the distribution of the net groundwater depletion. As is evident from Figures 21 and 22 of Gutentag et al., the depletion rate has been growing linearly with time since predevelopment around 1940. According to these the total accumulative water depletion can be approximated by the empirical relation $\Delta m(t) = -0.12 \times 10^{12}\, t^2$ kg, where t is the number of years since 1940.

The geographical centroid of this water depletion (judging from Figure 23 of Gutentag et al.) lies approximately at $\theta = 36°$N and $\lambda = 102°$W. Equation (1) (with ocean correction) then gives the resultant polar drift, cumulative to date (1987) since 1940: 3.8 mas in the direction of 101°W (Table 3). Taking the time derivative leads to the (linearly increasing) rate of this polar drift since 1940: (3.46×10^{-3} t) mas yr^{-1} toward 101°W. For example, the rate in 1987 is 0.16 mas yr^{-1}. The drift rate will grow linearly with time if current acceleration in the groundwater pumpage continues. If the entire aquifer were depleted, the rotational pole would shift toward 101°W by as much as 60 mas, corresponding to 1.8 m on the Earth's surface.

5. Conclusions and Discussion

We have computed the excitation of the Earth's polar motion due to mass variations in major continental hydrological reservoirs. The results provide "corrections" to previous hydrological excitation estimates, which neglect reservoir effects. Here we give further discussions with regard to the annual wobble, the Chandler wobble, and the (secular) polar drift:

1. Annual wobble excitation results (for natural lakes) in terms of ψ^+ and ψ^- are summarized in Table 3 and plotted in Figure 5. Their vector sums are also given, as "SUM": $\psi^+ =$ (0.52 mas, $-150°$) and $\psi^- =$ (0.48 mas, $-35°$).

For comparison, Table 3 also gives other annual wobble excitation estimates. "SNOW," adopted from *Chao et al.* [1987], is the contribution from continental snow load estimated from satellite remote sensing data; "RAIN" is the contribution from the rainfall and evapotranspiration estimated by *Chao and O'Connor* [1988*b*] using a conventional data set (while neglecting reservoir effects); and "SNOW + RAIN" is their vector sum. "ILS" is the observed annual wobble excitation from the International Latitude Service data for 1900–1977 (as determined by *Wilson and Vicente* [1980]); "LAGEOS" is that from the LAGEOS satellite laser ranging data for 1977–1986 [*Pavlis et al.*, 1987], obtained here from a least squares fit of annual signals to the (deconvolved) polar motion excitation function. ILS and LAGEOS represent two independent estimates for two different time spans. They agree well in the better determined component ψ^+, but less so in the poorly determined ψ^-. They are known to be caused primarily by atmospheric variations (see section 1).

Note the small amplitude of (SNOW + RAIN) owing to the large cancellation between the SNOW and RAIN contributions [*Chao and O'Connor*, 1988*b*]. Given this, it is then interesting to compare (SNOW + RAIN) with SUM, our estimate for the total lake contribution. It is seen that the ψ^+ component of SUM has a magnitude that is nearly 30% of

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TABLE 3. Annual Wobble Excitation and Polar Drift Caused by Mass Variations of Major Lakes, Artificial Reservoirs, and the North American High Plains Aquifer

	Annual Wobble Excitation, mas			Polar Drift, mas		
	Ψ^+	Ψ^-	$\lvert\Psi\rvert$	Δm^a	Ψ	Years
Natural lake[b]						
2,5,6,12,14	(0.35, −136°)	(0.37, −29°)	0.72	320	4.5[c]	Fluctuated
8,11,13	(0.059, −127°)	(0.069, −90°)	0.13	40	0.5[c]	Fluctuated
1	(0.18, 148°)	(0.18, −47°)	0.36	−1080	(17.9, 51°E)	1930–1955
4	(0.11, −96°)	(0.11, −144°)	0.21	−173	(2.9, 60°E)	1960–1970
9	(0.055, 96°)	(0.055, 114°)	0.11		(See Table 2)	
3			0.014[d]	+140	(0.04, 40°W)	1961–1964
7			0.027[d]	+95	(0.25, 23°E)	1961–1964
10			0.048[d]	+135	(0.77, 32°E)	1915–1935
15	(0.037, 61°)	(0.037, 61°)	0.094			
16				−48	(0.80, 76°E)	1910–1950
17	(0.18, −130°)	(0.18, 16°)	0.36[d]			
18	(0.14, 44°)	(0.14, 164°)	0.27[d]			
19				+77	(0.61, 166°W)	1940–1970
20				+−31	0.42[c]	1949–1951
21				18	0.28[c]	Fluctuated
Artificial reservoirs				+2600	(9.3, 122°W)	1952–1986
NA High Plains Aquifer				−265	(3.8, 101°W)	1940–1987
SUM	(0.52, −150°)	(0.48, −35°)	1.0		(10.2, 35°E)	
SNOW	(4.9, −109°)	(4.8, −28°)	9.7			
RAIN	(3.6, 54°)	(4.2, 110°)	7.[illegible]			
SNOW + RAIN	(1.9, −74°)	(3.3, 29°)	5.2			
ILS	(15.7, −64°)	(19.9, −144°)	···		(3.5 mas yr^{-1}, 80°W)	1900–1980
LAGEOS	(17.6, −67°)	(7.7, −107°)	···		(4.3 mas yr^{-1}, 44°W)	1977–1986

Also listed for comparison are those computed for "SNOW" [*Chao et al.*, 1987], "RAIN," and their vector sum [*Chao and O'Connor*, 1988*b*], as well as those observed from the ILS and LAGEOS polar motion data. The annual wobble prograde component Ψ^+ and retrograde component Ψ^- refer to January 1.

[a]Secular or interannual peak-to-peak change in water mass during this century, in 10^{12} kg (or km^3).

[b]Numbers refer to Table 1.

[c]Peak-to-peak fluctuation along the lake meridian, not included in Figure 6.

[d]Nominal.

that of (SNOW + RAIN). As far as the total hydrological excitation is concerned, this is a significant fraction which obviously should not be neglected.

2. Chandler wobble excitation has been estimated for two cases where multiyear time series with monthly sampling are available: the NA Great Lakes (section 2.2) and the artificial reservoirs (section 3). The excitation power of the NA Great Lakes is as much as 40 dB lower than that required to drive the observed Chandler wobble for the period 1962–1986. The average power envelope (see section 3) of the artificial reservoirs appears even lower. Other hydrological reservoirs (primarily natural lakes) presumably have even less contribution, judging from their performance with respect to the annual wobble excitation. Thus, during 1962–1987 the hydrological reservoirs had a low contribution to the Chandler excitation, presumably no more than 2–3%. However, this level of exci-

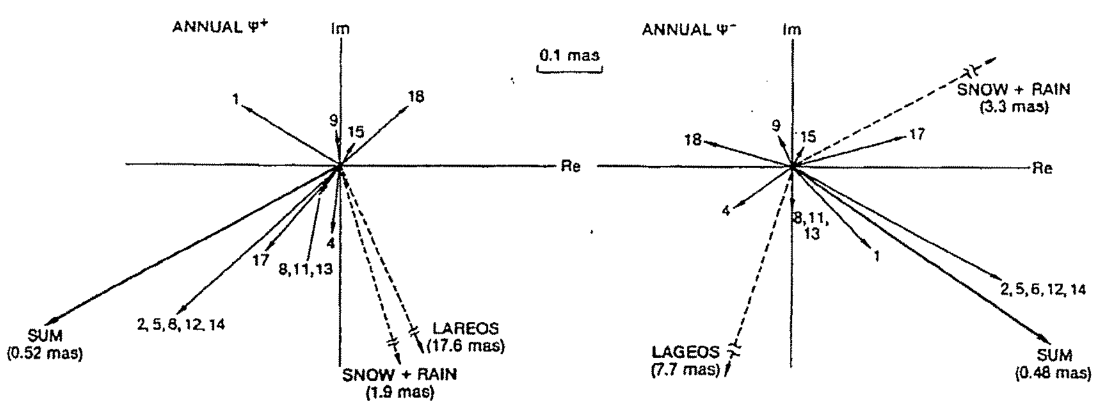

Fig. 5. Annual wobble excitation estimates in terms of ψ^+ and ψ^-, the prograde and the retrograde components, respectively, of January 1. Those due to annual water mass variations of the natural lakes are indicated by numbers referring to Table 1; their vector sum by the heavy arrow SUM. The (SNOW + RAIN) and LAGEOS estimates (refer to Table 3) are also plotted (the dashed arrows) as reference.

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tation is still more than 10 dB higher than the average Chandler excitation power provided by earthquakes during 1977–1983 [*Gross*, 1986].

3. Secular polar drift caused by water mass variations in major lakes, artificial reservoirs, and the NA High Plains groundwater aquifer is listed in Table 3. Figure 6 shows the (secular) contributions that exceed 1 mas. The vector sum which gives the net secular drift (shown as SUM) is (10.2 mas, 35°E). It does not include those lakes (indicated by footnote c in Table 3) whose levels fluctuated erratically rather than secularly.

Table 3 and Figure 6 also show the observed yearly mean rate of polar drift: 3.5 mas yr^{-1} in the direction of 80°W based on 80 years of ILS data (as determined by, e.g., *Chao* [1983]), and 4.3 mas yr^{-1} in the direction of 44°W according to 10 years of LAGEOS data (as described above), obtained here from a least squares estimation of the linear trend. The ILS polar drift rate has been shown to be consistent with the effect of the postglacial rebound and some reasonable viscosity models of the mantle [*Sabadini and Peltier*, 1981; *Wu and Peltier*, 1984].

By comparison, the polar drift caused by the drastic lowering of the Caspian Sea level during 1930–1955 reached a rate of about 1/5 of the ILS mean rate in a direction ~130° to the east. This, however, has been nullified partially and subsequently by the effects of the water impoundment of artificial reservoirs and the depletion of the NA High Plains Aquifer. As a result, in this century, hydrological reservoirs (that we studied) have only contributed an insignificant net amount of secular polar drift, in a direction which is some 90° east from the observed mean direction. Note, nevertheless, that this cancellation is fortuitous and the hydrological reservoirs are potentially capable of producing significant polar drift when conditions allow.

Throughout our study, the cutoff lower limit on the mass

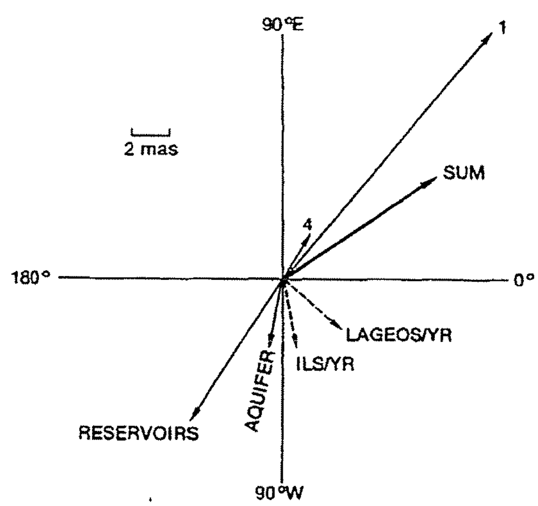

Fig. 6. Secular polar drift estimates in the geographical coordinates. For the natural lakes, only the dominant Caspian Sea and Aral Sea are plotted. The SUM (heavy arrow) gives the vector sum of all the natural lakes, the artificial reservoirs, and the NA High Plains Aquifer (refer to Table 3). Also plotted (the dashed arrows) for comparison are the yearly rate of the polar drift according to the ILS data (1900–1980) and the LAGEOS satellite data (1977–1986).

variation is set to be $\sim 10^{13}$ kg for the corresponding excitation to be significant, and the temporal scale of the variation is limited to less than a few decades so that the Earth can be treated as an elastic body. We have strived to be exhaustive, although it is still not certain to what degree our reservoir list is complete, especially with respect to the water variation in remote, extended wetland areas of the world. For a complete survey the most efficient way may be a remote-sensing monitoring from Earth-orbiting satellites, such as the proposed Earth Observing System [*NASA*, 1984].

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** TOTAL PAGE. 11 **

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them I found $\frac{\mathfrak{P}_2}{\beta A}=\frac{1}{141}$, and $\mathfrak{P}_1=0$; and in the other $\mathfrak{P}_1=\mathfrak{P}_2=0$. In order not to interrupt the thread of the argument, the calculation is given in Appendix A; it will also be more intelligible after the latter part of this paper has been read. In the general case the same kind of proportion will subsist between $\mathfrak{P}_1$ and $A\alpha$, $\mathfrak{P}_2$ and $A\beta$, and we may therefore, without serious error, neglect the former compared with the latter.

Thus, as far as concerns the present inequality,

$$\omega_1=\frac{n\alpha}{\mu}(1-\cos\mu t)-\frac{n\beta}{\mu}\sin\mu t,$$

$$\omega_2=\frac{n\alpha}{\mu}\sin\mu t+\frac{n\beta}{\mu}(1-\cos\mu t).$$

On account of this inequality the greatest angular distance (in radians) of the instantaneous axis from the pole is $\frac{2\sqrt{\alpha^2+\beta^2}}{\mu}$. It will appear from the latter part of this paper that, if the elevation of a large continent proceeds at the rate of two feet in a century, $\sqrt{\alpha^2+\beta^2}$ may be about $\frac{1}{100}''$ per annum, and μ is $360°$ in 306 days; whence it follows that the greatest angle made by the instantaneous axis with the axis of figure is comparable with $\frac{1}{370}''$, a quantity beyond the power of observation. On the score of these terms the instantaneous axis will therefore remain sensibly coincident with the axis of figure.

They will, moreover, produce no secular alteration on the obliquity of the ecliptic, nor in the precession, because they will appear as periodic in $\frac{d\theta}{dt}$ and $\frac{d\psi}{dt}\sin\theta$, with arguments n and $n\pm\mu$.

Now although this inequality is so small, it nevertheless is of interest.

If we map, on a tangent plane to the earth at its initial pole, the relative motion of the instantaneous axis and the pole of figure, we get, as the equation to the curve,

$$x=\frac{\alpha}{\mu}(1-\cos\mu t)-\frac{\beta}{\mu}\sin\mu t,$$

$$y=\frac{\alpha}{\mu}\sin\mu t+\frac{\beta}{\mu}(1-\cos\mu t).$$

If t be eliminated from these equations, we get

$$\left(x-\frac{\alpha}{\mu}\right)^2+\left(y+\frac{\beta}{\mu}\right)^2=\frac{\alpha^2+\beta^2}{\mu^2}.$$

Thus the relative motion is a circle, passing through the origin, and touching a line inclined to the axis of y at an angle arc $\tan\frac{\alpha}{\beta}$. Therefore the instantaneous axis describes a circle passing through the pole of figure every 306th day; and this circle touches the

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Anthropogenic impact on global geodynamics due to reservoir water impoundment

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Abstract. Water impounded in artificial reservoirs since ~1950 is by far the largest anthropogenic hydrological change in terms of the mass involved. This mass redistribution contributes to geodynamic changes in the Earth's rotation and gravitational field that have been closely monitored by modern space geodetic techniques. We compute the effect of 88 major reservoirs on length-of-day, polar motion, and low-degree gravitational coefficients. On an individual basis much smaller than geophysical signals in scale and magnitude, these anthropogenic effects prove to be non-negligible cumulatively, especially when considering the fact that our results represent underestimates of the reality. In particular, reservoir water has contributed a significant fraction in the total observed polar drift over the last 40 years.

Introduction

Human activities have greatly altered the living environment throughout history. One of the most significant alterations is water management that has been administered on land. Among various types of water management projects, the artificial reservoirs are by far the largest in terms of the amount of water involved [e.g., *Chao*, 1991].

Ever since the early 1950s, the world has seen intensive construction of artificial reservoirs. In a study of the anthropogenic impact on sea level, *Chao* [1991] estimated that, growing essentially linearly, the amount of water impounded in these reservoirs by the early 1990s have reached as much as 10,000 km^3, or 10^{16} kg. This is as much water as there is total atmospheric moisture or equivalent to 10 times the Earth's biological water, and greatly exceed the 1,900 km^3 compiled by *Sahagian et al.* [1994] which has been considered as a gross underestimate [*Chao*, 1994; *Rodenburg*, 1994]. Ultimately removed from the ocean, it has lowered the sea level by about 3 cm, equivalent to an average rate of sea level drop of 0.7 mm per year over the past 40 years.

The water mass redistribution due to the artificial reservoirs also has impact on global geodynamics in two distinct effects: It changes the moment of inertia, and hence the rotation of the Earth under the conservation of angular momentum. It also changes the external gravitational field according to Newton's gravitational law. The Earth rotational change is conveniently expressed in terms of its magnitude, or the length-of-day (LOD) variation, and its orientation in the terrestrial reference frame, or the polar motion excitation. The gravitational changes are expressed in terms of the variation of the harmonic coefficients of the gravitational potential field. These are the specific geodynamic quantities we will compute.

Chao [1988] has computed the polar motion excitation produced by a host of major hydrological changes including those due to major artificial reservoirs in the world completed before 1986. Building upon the latter, we will in this paper compute and discuss not only the polar motion excitation but also LOD and low-degree gravitational changes due to a more complete and up-to-date list of major reservoirs.

Data and Computation

We have compiled a tally of 88 major reservoirs that exceed 10 km^3 in capacity from four different sources. Two of them, *Van der Leeden* [1975] and *U.S. Department of the Interior* [1983], led to 53 major reservoirs previously listed and employed by *Chao* [1988]. Two additional sources, *U.S. Department of the Interior* [1988] and *International Water Power & Dam Construction Handbook* [1993], provide supplementary as well as more up-to-date tally. Figure 1 shows their geographical distribution and relative sizes in logarithmic scale. The corresponding cumulative water impoundment is shown in Figure 2. The growth of the amount of water over time is virtually linear since 1950, showing no sign of slowing down.

The computations conducted below in this paper pertain to these major reservoirs. The water mass redistribution is modeled as an instantaneous addition of a point mass equal to the full capacity at the reservoir location in the year of its completion, minus an accompanying eustatic drop in the sea level to conserve the total water mass (see the inside scale of Figure 2). The formulae for computing changes of the geodynamic quantities due to the addition of a point mass m at location (latitude θ, longitude λ) are of the general form:

$$\Delta Q = q(\theta,\lambda)\ m\ /\ (\text{mass of Earth}) + [\text{ocean correction}]. \quad (1)$$

The function $q(\theta,\lambda)$ is the geographical weighting function depending on the parameter in question.

For the change in the normalized harmonic coefficients of the gravitational field, or the (complex) Stokes coefficients $C_{lm} + iS_{lm}$ of degree l and order m, $q = [(1+k_l')/(2l+1)]P_{lm}(\theta)\exp(im\lambda)$ [e.g., *Chao and O'Connor*, 1988], where P_{lm} is the 4π-normalized Legendre function, and the factor $1+k_l'$ (where k_l' is the load Love number, e.g., $k_2' = -0.31$, $k_3' = -0.20$, $k_4' = -0.13$, etc.) accounts for the elastic yielding effect of the Earth under loading. In particular, the un-normalized zonal "J" coefficients are given by $J_l = -(2l+1)^{1/2}\,C_{l0}$.

The LOD change in units of μs can be directly evaluated by multiplying 1.96×10^{11} to the change in J_2. This is because the two changes are proportional to each other as long as the mass

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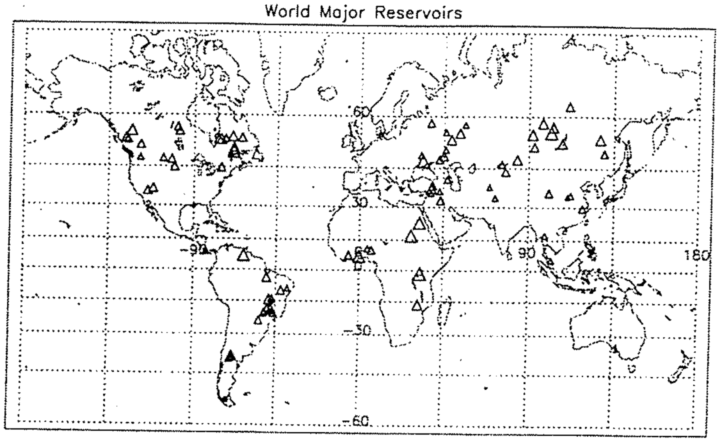

Figure 1. The geographical distribution of 88 major reservoirs and their relative sizes in logarithmic scale.

redistribution occurs on the surface of the Earth which can be well approximated by a spherical shell (so that the change in the trace of the inertia tensor vanishes subject to the conservation of mass, see *Chao and O'Connor* [1988]). Here it is assumed that the fluid core is decoupled from the mantle in the excitation process that is rapid compared to the characteristic time for the Earth's visco-elastic responses.

The polar motion excitation is often expressed in the complex quantity $\Psi = \Psi_x + i\Psi_y$ where x and y axes point to the Greenwich Meridian and the 90°E longitude in the terrestrial coordinate system. Its geographical weighting function is $q = -1.12 \sin\theta \cos\theta \exp(i\lambda) / J_2$, proportional to the change in the Stokes coefficients of degree 2 and order 1. The point-mass excitation is most effective at the 45° latitudes and zero at the poles and the Equator, whereas two equal masses located on the same latitude but 180° apart in longitude, such as Canada and Siberia (cf. Figure 1), will cancel each other. The factor 1.12 takes into account the elastic yielding effect and the decoupling of the core. The polar motion excitation enjoys the magnification by the factor $1/J_2$ (where $J_2 = 1.083 \times 10^{-3}$ is the Earth's dynamic oblateness), because the system "inertia" that it needs to overcome is only the difference between the axial and equatorial moments of inertia of the Earth (as opposed to the axial moment of inertia itself in the case of the LOD).

An ocean correction term is invoked in Equation (1) to conserve water mass. It is assumed that the water impounded in reservoirs ultimately comes from the ocean (by way of the atmosphere), resulting in an instantaneous, uniform eustatic drop of sea level. This term is computed according to *Chao and O'Connor* [1988] (an extra factor of 1.12 is introduced to LOD

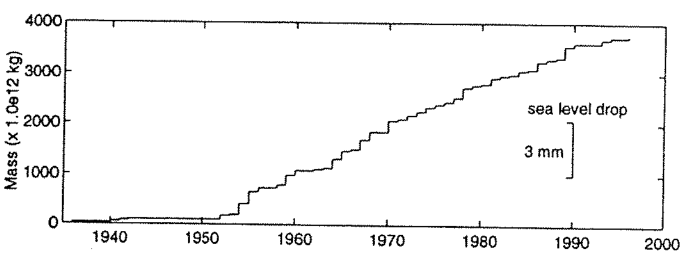

Figure 2. The cumulative impoundment of reservoir water over time. The inside scale gives the equivalent eustatic sea-level drop.

and polar motion excitations to account for the decoupling of the core). The ocean correction is typically no more than a tenth of the point-mass contribution, because the water distribution involved is wide spread and hence less effective than point masses. In addition, the actual motion of the (water) mass transport also excites Earth rotational variations. However, this contribution in our present case is negligible as the motion (from ocean to the reservoirs) is a relatively slow process.

As a rule of thumb from Equation (1), a point mass equivalent to 100 km^3 of water (as with the very largest reservoirs) will only produce a LOD change on the order of 1 µs, a polar motion excitation on the order of 1 milliarcsecond (mas), and a J_2 change on the order of 10^{-11}. We shall examine the *cumulative* effects computed simply by sequentially summing up the 88 individual contributions over time: $\Delta Q(t) = \sum_i \Delta Q_i\, H(t-t_i)$, where H indicates the Heaviside function and t_i is the completion time (in nominal year) of the ith reservoir.

Results and Discussion

We compute the changes induced by the 88 reservoirs in the three degree-1 Stokes coefficients (C_{10}, C_{11}, S_{11}), the five degree-2 Stokes coefficients (J_2, C_{21}, S_{21}, C_{22}, S_{22}), and the zonal coefficients of degree 3 and 4 (J_3, J_4). As stated, the change in LOD is proportional to that of J_2, and the polar motion excitation is proportional to the change in $C_{21} + iS_{21}$. Higher harmonic changes, which tend to be smaller in magnitude because of geographical cancellations, are of less interest as they are not subject to direct observations.

Figure 3 shows the reservoir-induced, cumulative changes in C_{10}, C_{11}, and S_{11}, converted to distance (in mm) by multiplying the Earth's mean radius and inverting the sign. Respectively they represent the z, x, and y components of the shift of the "geocenter" location. The center of mass of the total system of [solid Earth + reservoirs] remains unchanged as the reservoirs are filled, of course. Therefore, the center of mass of the solid Earth, or geocenter, shifts in the opposite direction to the net water mass shift (which is toward the northern hemisphere and the positive x direction). The geocenter shift can be detected by space geodetic measurements made at geodetic stations, which

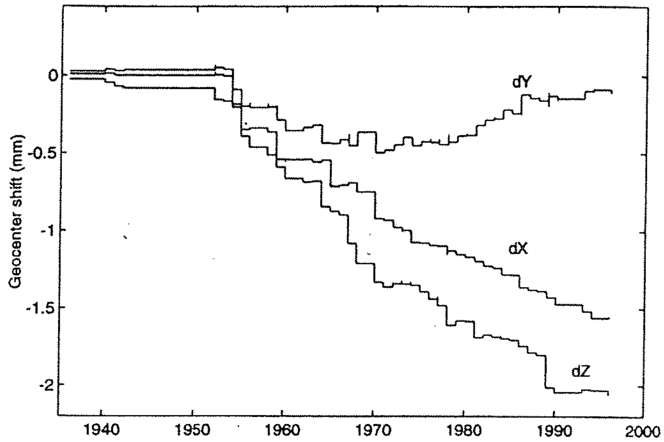

Figure 3. Geocenter shift due to world's major reservoirs.

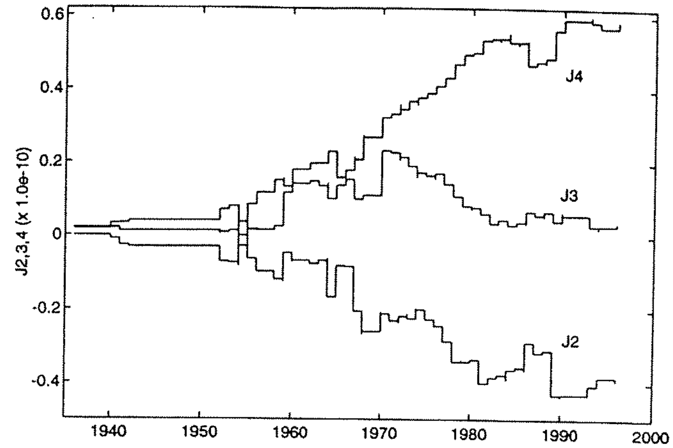

Figure 4. Changes in the Earth's zonal gravitational coefficients J_2, J_3, and J_4 due to world's major reservoirs.

are fixed w.r.t the solid Earth. The total reservoir-induced shift of about 3 mm is comparable in magnitude to the rms center-of-mass fluctuations caused by the seasonal atmospheric mass redistribution [R. S. Nerem, personal communication, 1995].

Figure 4 shows the cumulative changes in the zonal J_2, J_3, and J_4. In particular, the reservoirs caused the Earth's dynamic oblateness J_2 to decrease at the rate of about -1.0 x 10^{-12} per year since ~1950. This quasi-secular rate is an order of magnitude larger than the earthquake-induced counterpart at about -0.2 x 10^{-12} per year averaged over 1977-1993 [*Chao et al.*, 1995]. In comparison, the observed secular rate of J_2 determined from laser ranging to Lageos satellite is about -26 x 10^{-12} per year, whereas the rms seasonal fluctuation of J_2 is even larger at about 200 x 10^{-12} [e.g., *Nerem et al.*, 1993]. The former has been attributed to the post-glacial rebound and polar ice sheet variations, and the latter is primarily a consequence of atmospheric mass redistributions. Similarly, the overall reservoir-induced variation in J_3 is two orders of magnitude smaller than that observed by Lageos.

Figure 5 gives the cumulative changes in J_{22} and ϕ_{22}, defined by $J_{22} \exp(i2\phi_{22}) = C_{22} + iS_{22}$. As shown by *Liu and Chao* [1991], J_{22} is a normalized positive difference between the two equatorial principal moments of inertia, while ϕ_{22} is the longitude of the (equatorial) principal axis of the least moment of inertia. Their changes can be easily evaluated from the Earth's existing C_{22} and S_{22} and changes thereof. The reservoir-induced J_{22} shows a decreasing trend at the rate of about -0.6 x 10^{-12} per year for the last 40 years. Like J_2, this rate is an order of magnitude larger than the earthquake-induced counterpart during 1977-1993. The reservoir-induced change in the angle ϕ_{22} has, to date, reverted to its original value after peaked at some 1.4 arcseconds in the 1970s.

The reservoir-induced LOD change is proportional to that of J_2. The cumulative change is shown in Figure 6, displaying an average rate of about -0.2 μs (in each day) per year for the past 40 years. Although hardly noticeable even in modern measurements, this rate is about twice that due to earthquakes during 1977-1993 [*Chao and Gross*, 1995]. It is interesting to examine the physics of the process. The net water transport has been toward high latitudes (cf. Figure 1); J_2 reduces as a result and so does the Earth's axial moment of inertia. Like a spinning skaters drawing her arms toward her body, the Earth spins faster under the conservation of angular momentum (hence shorter LOD), and the kinetic energy of the spin increases in the process. The ultimate source of this energy is the solar energy transferred by way of the meteorological heat engine. It is easy to show [*Chao and Gross*, 1995] that the average rate of this spin energy increase is $+10^{18}$ joul per year, or about 30 gigawatt, equivalent to about 3% of the total human power consumption. In comparison, the average rate of seismic wave energy release during 1977-1993 is about 5 gigawatt.

Figure 7 shows the polar motion excitation function Ψ. Despite a considerable geographical cancellation, both x and y components show a quasi-secular trend. Thus, the filling of major reservoirs over the past 40 years has caused the mean rotational pole to drift some 20 mas, amounting to an average of 0.5 mas per year, toward ~130°W. The observed polar drift over the same period is estimated to be 3.2 mas per year in the direction of 81°W [R. S. Gross, personal communication, 1994]. The reservoirs have thus contributed a significant fraction in the observed polar drift, in roughly the same general direction. This should be taken into consideration in studies with respect to the geophysical causes of the polar drift.

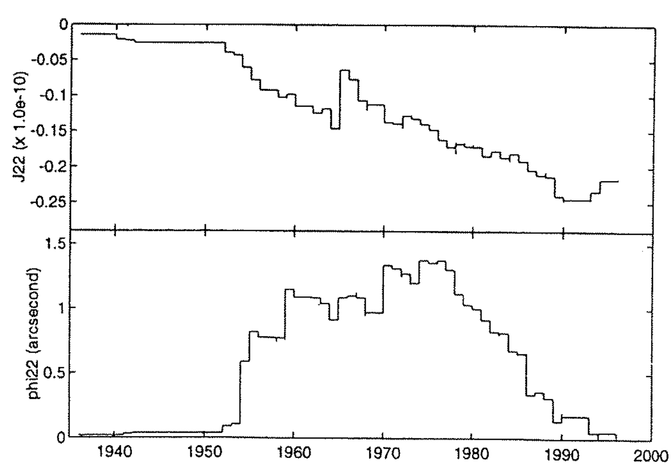

Figure 5. Changes in the Earth's equatorial moments of inertia due to world's major reservoirs.

APPENDIX C

1. *Ex Parte William T. Carpenter*, Decision on Appeal, Appeal No. 2006-0089.

The opinion in support of the decision being entered today was not written for publication and is not binding precedent of the Board.

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE BOARD OF PATENT APPEALS
AND INTERFERENCES

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U.S. PATENT AND TRADEMARK OFFICE
BOARD OF PATENT APPEALS
AND INTERFERENCES

Ex parte WILLIAM T. CARPENTER

Appeal No. 2006-0089
Application No. 09/773,815

ON BRIEF

Before FRANKFORT, BAHR and NAPPI, Administrative Patent Judges.
FRANKFORT, Administrative Patent Judge.

DECISION ON APPEAL

This is a decision on appeal from the examiner's final rejection of claims 11 through 20, all of the claims remaining in the application. Claims 1 through 10 have been canceled.

Appellant's invention relates to a method for modifying the axis of rotation of a planet by the redistribution of mass in or on the planet's crust. Claim 11, the only independent claim remaining, is representative of the subject matter on appeal and reads as follows:

11. A method of modifying the axis of rotation of a planet comprising the steps of:

measuring the mass of a planet;

determining the center of mass of the planet;

characterizing the axis of rotation of the planet;

selecting a desired character of rotation;

calculating a moment of stability required to cause the desired character of rotation;

determining a position and a mass of a compensating substance sufficient to effect the moment of stability; and

positioning the mass in the position.

The references of record relied upon by the examiner in rejecting the appealed claims are[1]:

White, "Pole Shift: Predictions and Prophecies of the Ultimate Disaster", Doubleday & Company, Inc. (1980).

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[1] The examiner mistakenly indicates on page 3 of the answer that "[n]o evidence is relied upon by the examiner in the rejection of the claims under appeal."

Chao, "Anthropogenic impact on global geodynamics due to reservoir water impoundment", Geophysical Research Letters, vol. 22, no. 24, pgs. 3529-3532 (December 15, 1995).

Brown, "Cataclysms of the Earth", Twayne Publishers Inc., pages 151-156 (1996).

Claims 11 through 20 stand rejected under 35 U.S.C. § 112, first paragraph, as failing to comply with the enablement requirement. In the examiner's view, the claims contain subject matter which was not described in the specification in such a way as to enable one skilled in the art to which it pertains, or with which it is most nearly connected, to make and/or use the invention.

Claims 11 through 20 also stand rejected under 35 U.S.C. § 103(a) as being unpatentable over Chao in view of White and Brown.

Rather than reiterate the examiner's full statement of the above-noted rejections and the conflicting viewpoints advanced by the examiner and appellant regarding those rejections, we make reference to the examiner's answer (mailed July 5, 2005) for the examiner's reasoning in support of the rejections, and to

appellant's brief (filed April 11, 2005) and reply brief (filed September 6, 2005) for the arguments thereagainst.

OPINION

In reaching our decision in this appeal, we have given careful consideration to appellant's specification and claims, to the applied prior art references, and to the respective positions articulated by appellant and the examiner. As a consequence of our review, we have made the determinations which follow.

We turn first to the examiner's rejection of claims 11 through 20 under 35 U.S.C. § 112, first paragraph, as being based on a non-enabling disclosure. It is by now well-established law that the test for compliance with the enablement requirement in the first paragraph of 35 U.S.C. § 112 is whether the disclosure, as filed, is sufficiently complete to enable one of ordinary skill in the art to make and use the claimed invention without undue experimentation. Note, In re Moore, 439 F.2d 1232; 169 USPQ 236 (CCPA 1971). See also In re Scarborough, 500 F.2d 560, 182 USPQ 298 (CCPA 1974) and In re Wands, 858 F.2d 731, 737, 8 USPQ2d 1400, 1404 (Fed. Cir. 1988). Moreover, in rejecting a

claim for lack of enablement, it is also well settled that the examiner has the initial burden of advancing acceptable reasoning inconsistent with enablement in order to substantiate the rejection. See In re Strahilevitz, 668 F.2d 1229, 212 USPQ 561 (CCPA 1982); In re Marzocchi, 439 F.2d 220, 169 USPQ 367 (CCPA 1971). Once this is done, the burden shifts to appellant to rebut this conclusion by presenting evidence to prove that the disclosure in the specification is enabling. See In re Doyle, 482 F.2d 1385, 179 USPQ 227 (CCPA 1973); In re Eynde, 480 F.2d 1364, 178 USPQ 640 (CCPA 1973).

In the case before us, after reviewing the disclosure as set for in the specification, we are of the opinion that the examiner has not met his burden of advancing acceptable reasoning inconsistent with enablement. The examiner's position is set forth on pages 3 and 4 of the answer and essentially questions the ability of one skilled in the art to calculate "a moment of stability required to cause the desired character of rotation" given that the specification fails to disclose any equations or methods to perform such a calculating step. The examiner also poses the question of how a mass sufficient to achieve the desired change in the axis of rotation of a planet would be

captured and positioned to effect the desired moment of stability, and asks how long such a process would take.

Like appellant, given the state of the art as exemplified by Chao, White and Brown, and the disclosure of the present application, we have no doubt that one skilled in the pertinent art would be able to calculate a moment of stability required to cause a desired character of rotation and otherwise perform the claimed method without resort to undue experimentation. Note, pages 3-5 of the brief and pages 3 and 4 of the reply brief for appellant's arguments and comments.

Looking to the article by Chao, even though it does not specifically address a method like that claimed by appellant, it is clear that the level of skill in the art of global geodynamics is very high and that one skilled in the art would be able to calculate the relevant quantities required in independent claim 11 on appeal, including calculating a moment of stability required to cause a desired character of rotation. As for the examiner's concerns regarding capturing a mass of sufficient size, the time needed to do so, and the exact manner of positioning that mass in its predetermined location, both

appellant's specification and Chao provide reasonable answers to those questions, especially given the broad scope of the claims.

With particular regard to the scope of the claims, we note appellant's indication at page 4, lines 25-26 of the specification that "[t]he amount of mass altered would be dependent upon the desired change to the Earth's center of mass and consequent changes to the axis of rotation." Thus, even a relatively minor change or modification in the axis of rotation would fall within the bounds of the claims on appeal. We also note appellant's disclosure at page 5, wherein it is indicated that

> In the best embodiment of the invention, water from the worlds oceans is contained in cavities or reservoirs either above ground or underground or both. Since the rotating Earth has a gravitational field that overpowers the centrifugal forces, at the crust's radius, that are caused by the rotation of our planet, it is unique from the sphere rotating on Earth. This gravitational field can hold a fluid mass in place on the surface of the Earth. This fluid mass, so held in place, tends to distribute and redistribute itself relatively equally over the surface of the oceans in which it is laterally contained, in conformity with the combined effects of the extraneous gravitational variations caused by the Sun, Moon, and other planets. Therefore this fluid mass of the oceans is the most ideal material to use for the redistribution mass because a portion of this fluid mass can be placed at some predetermined location, which would cause an actual redistribution of mass of the entire planet,

> because the remainder of this fluid mass of the oceans would then equally redistribute itself throughout the above referenced surface.
>
> Capturing and removing of any portion of the fluid mass of the oceans would cause the remaining mass to be proportionately diminished. However, this diminishment would be equally diminished over the entire surface of the interconnected oceans of the planet and only the fluid, or sea, level would be effected. Therefore actual redistribution of mass of a planet can occur by moving a portion of this fluid mass from the area where it can redistribute itself and containing this removed portion in a manner where it cannot redistribute itself. Selectively containing any portion of this removed fluid mass in a predetermined, or any, location would thereby change the center of mass of the Earth and, since it is rotating in inertial space, thereby cause the axis of rotation to be altered. Such change in the axis of rotation changes the relationship to the Sun, Moon and other planets and would effect the Earth's climatic pattern due to the change in angle of incidence to the Sun.

In the final analysis, we agree with appellant that it appears the examiner has confused the question of enablement with the issue of the difficulty (economically and timewise) of carrying out the disclosed and claimed method. The examiner has made no attempt to explain exactly why one of ordinary skill in the art would have been unable to calculate the relevant quantities and subsequently carry out the steps of the recited method via known engineering techniques.

Thus, for the above reasons, we will not sustain the examiner's rejection of claims 11 through 20 under 35 U.S.C. 112, first paragraph, as being directed to a non-enabling disclosure.

We next consider the examiner's rejection of claims 11 through 20 under 35 U.S.C. § 103(a) as being unpatentable over Chao in view of White and Brown. Chao looks at human's impact on global geodynamics due to reservoir water impoundment since 1950, noting that such mass redistribution due to artificial reservoirs impacts global geodynamics by changing the Earth's moment of inertia and hence the rotation of the Earth under the conservation of angular momentum, thereby contributing a fraction to the phenomenon of "polar drift." Brown and White both discuss the problem of the continual growth of the South Polar icecap creating a distortion, or wobble, in the Earth's normal spin, and hypothesize that every six to eight thousand years such growth can cause a sudden and radical shift in the Earth's axis of rotation, thereby causing continents and sea areas to be cataclysmically rearranged creating what the authors characterize as the "ultimate disaster." Although these references all recognize that the Earth's axis of rotation is slowly changing and that such changes induced by both humans and nature will

alter the Earth's living environment, none of them contemplates, teaches or suggests the particular method of claims 11 through 20 on appeal as a solution to the Earth's changing rotational orientation.

Nor do the applied references collectively teach or suggest appellant's claimed pro-active method involving the steps of measuring the mass of the planet, determining the center of mass of the planet, characterizing the axis of rotation of the planet, selecting a desired character of rotation, calculating a moment of stability required to cause the desired character of rotation, determining a position and a mass of a compensating substance sufficient to effect the moment of stability, and positioning the mass in the position. For that reason, we will not sustain the examiner's rejection of claims 11 through 20 under 35 U.S.C. § 103(a).

Since neither of the rejections before us on appeal has been sustained, it follows that the decision of the examiner is reversed.

REVERSED

Charles E. Frankfort

CHARLES E. FRANKFORT Administrative Patent Judge	)	
Jennifer D. Bahr JENNIFER D. BAHR Administrative Patent Judge	)	BOARD OF PATENT APPEALS AND INTERFERENCES
ROBERT E. NAPPI Administrative Patent Judge	)	

what can examiner do after he/she is reversed?

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